## NANOTECHNOLOGY The Next Remediation Magic Bullet?

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#### AGENDA

- Definition
- Nanoremediation
- Nanoscale Zero Valent Iron
- Addressing Environmental Questions
- HydroQual Solution
- Conclusions







### THE STORY





#### **NANOTECHNOLOGY - DEFINITIONS**



Nanoscale particle: A subclassification of ultrafine particles with lengths in the 2-3 dimensions greater that 0.001 μm (1 nm) and less than 0.1 μm (100 nm) which may or may not exhibit a size related intensive property.

ASTM E2456-06, 2007

 Nanotechnology: The design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometer scale.

ROYAL SOCIETY/ROYAL ACADEMY OF ENGINEERING WORKING GROUP, 1994

- Nanoremediation: The use of nanotechnology in the improvement of a contaminated site to prevent, minimize or mitigate damage to human health or the environment.
- Nanotoxicology: The science of engineered nanodevices and nanostructures that deals with their effects in living organisms ENVIRONMENTAL HEALTH PERSPECTIVES, 2005, 113(7): 823 - 839.





#### **A NANO SCALE**



Adapted from: www.w5online.co.uk/.../nanotechnology/Size%20chart%20spattes%20and%20ladders.doc-





#### NANOREMEDIATION

- Superfund Program
  - National Priorities List
    - 1255 Sites (USEPA, 2009)
      - Estimated clean up time: 30-35 years
      - Cost: \$250 billion
- The America Recovery & Reinvestment Act of 2009 (US EPA)
  - 1 Billion USD allocated to cleaning up hazardous waste sites
    - Strong emphasis on emerging technologies
- Nanotechnology as a tool to protect the environment
  - Pollution Prevention
    - Cleaner/Greener technologies
    - Smaller amounts of contaminants
  - Treatment
  - Clean up

Karn, et al. 2009





#### **NANOREMEDIATION** - vs Conventional Treatment



- Advantages vs. Convention treatments (dig/pump and dump)
  - No removal of groundwater or soil for ex situ tmt
  - Higher SA and Reactivity
    - SA: nZVI [20-40 m<sup>2</sup>/g] vs ZVI [1 m<sup>2</sup>/g] Wang and Zhang, 2003
      - Translation: 10 1000 greater reactivity
  - Movement into smalls spaces in the subsurface
  - Increased mobility and distribution
  - Uniquely tailored coatings and surfaces
  - Reduction of costs



http://www.parsenviro.com/nanofeaw-1.html

CASE STUDY – COST COMPARISON Manufacturing site in New Jersey Primary contaminants of concern are TCE and PCE				
REMEDIAL APPROACH	ESTIMATED COST			
Pump and Treat Reactive Barrier	\$ 4,160,000 \$ 2,200,000			
NanoFe Technology	\$ 450,000			
HydroQual Laboratories Ltd.				



#### **NANOREMEDIATION - Applications**





http://www.sti.nasa.gov/tto/Spinoff2008/er 4.html

- Nanomechanical Water Purification Device
  - Carbon Nanotube
    - Low Energy/Space Requirements
    - High Volumes
    - USEPA Testing
      - Bacteria **↓**99.9999%
      - Viruses **↓**99.99%
      - Cryptosporidium parvum
      - Giardia lamblia
      - Chemical contaminants (arsenic, lead, benzene, copper, dioxins, herbicides, mercury and endotoxins such as *E. coli* and *Salmonella*
    - Applications
      - Space
      - Disaster zones
      - War zones
      - Industrial
      - Household







#### **NANOREMEDIATION-** Applications

- Zinc Oxide Notredame University
  - Sense and Shoot Approach
  - Treatment of Groundwater
    - Kamat et al., 2002
- Protein Biochips Purdue University
  - Sensing technology
  - [low] of COC and organisms
  - Rapid/real time monitoring of contamination
    - M. Ladisch: Micro-Scale Detection of Biological Species in Micro-Fluidic Chips," was presented at the Nanoscience and Nanotechnology: Shaping Biomedical Research conference at the National Institutes of Health in Bethesda, Md., on June 25.
- Magnetic Nanorust Rice University
  - Arsenic removal
  - Magnetic contaminant recovery
    - Yavuz et al., 2006
- Emulsified ZVI NASA
  - Treatment of DNAPL/TCE

http://www.carsico.it/servizi/Carsico-EZVI.pdf







#### **NANOREMEDIATION - Applications**

PARTICLES

- Nanocrystalline Zeolite
- Activated Carbon Fibers
- Carbon Nanotubes
- Functionalized CNT
- SWCNT/MWCNT
- SAMMS
- TiO<sub>2</sub>
- Ni/Fe or Pd/Au
- Bimetallic NP
- Zero Valent Iron

- COC
  - Volatile Organic Compounds
  - Metals
  - Semi volatile organic compounds
- MEDIA TREATED
  - Sands and clayey silts
  - Soil
  - Soil & Groundwater
  - Groundwater
    - KARN ET AL., 2009







## NANOREMEDIATION

### NANOSCALE ZERO VALENT IRON (nZVI) A Case Study





- Dechlorination:
  - Chlorinated solvents (PCE, TCE)
  - PCBs, Pesticides
  - Dioxins
- Trihalomethanes
- Organic dyes
- Adsorption/precipitation
  - Metals (Cd, Co, Ni, Sn, Pb, Cu, Hg, Cr)
  - Arsenic

Surface water treatment – adsorption of viruses, bacteria & metals, treatment of nitrates, sulfates, and organics.





#### • 2002 North Carolina Industrial Site

Geology	Contaminants treated	Final contaminant concentrations	Slurry Concentration, Injection type, and ORP Data	Project Team Information
Durham Triassic Basin sandstone interbedded with siltstone	PCE, TCE, DCE, VC. Initial TCE concentration 14,000 µg/L	Over a 90% reduction of pre- injection baseline concentration at injection well and observation well. DCE concentrations reduced to near or below groundwater quality standards, with no accompanying increases in vinyl chloride concentrations.	BNP slurry concentration of 1.9 g/L; total slurry volume 6,056 L; average injection rate 0.6 gallons per minute; gravity feed. Initial ORP values about +100 mV; after 3 days -400 mV; maintained at -500 to -400 mV for more than 3 months	Pilot test designed and implemented by Golder Associates Inc. (Florin Gheorghiu, Jarrett Elsea); Tel. (856) 793-2005 and Lehigh University (Wei-Xian Zhang, Ph.D.) NCDENR Contact: Rob McDaniel

#### 2006 New York Industrial Site

Glacial till overburden lying above fractured sedimentary bedrock.

TCE 1,900 ug/L 55-83% reductions in TCE from 1,900 ug/L to 330 ug/L (an 83% decline), and from 750 ug/L to 340 ug/L (a 55% decline). nZVI slurry concentration of 10 to 20 g/L; Total nZVI injected 600 Kg; Pressurized injection using geoprobe rig. Pilot test designed and implemented by Golder Associates Inc. (Allen Kane, Florin Gheorghiu); Tel (610) 941-8173 NYSDEC Contact: Lawrence Thomas







- Quebec, Canada
- 4 km plume with several identified source areas
  - COCs include TCE, DCE and traces of VC
- After nZVI injection, ORP values drop <-400 mV, microbiologic diversity shifts</li>
  - TCE reduced by 50 60 % in **1 month**
  - TCE reduced by >80% after 10 months, no build-up of daughter products
  - After 10 months, DCE concentrations increasing, correlated to biological re-diversification
- Golder retained for full-scale implementation
  - In excess of 100,000 kg BNP proposed for treatment







#### **NANOREMEDIATION - NanoFE Plus™**







- North Slope Alaska
- Type of Particle: nZVI/Pd
  - Abandoned oilfield
  - Geology: Organics over Alluvial grounds
  - Media treated: Soil
  - COC: Trichloroethane ([max]: 58 444 ug/kg), Diesel Fuel
  - ↓ TCA by 60%
  - Duration of test: 40.5 hours
- Cape Canaveral, Florida Launch Complex 15
- Type of Particle: eZVI
  - Abandoned space launch complex
  - Geology: Silty region 45 ft below ground with DNAPL
  - Media treated: soil & groundwater
  - COC: TCE & Daughter compounds ([max]: 439 000 ug/L]
  - ↓ to 28 ug/L
  - Duration ongoing
    - Karns et al., 2009







### THE ENVIRONMENTAL IMPLICATIONS AND RISKS





#### **NANOTECHNOLOGY - Why are we concerned?**

- Positive attributes = Negative Effects on Environment?
  - What is the fate and effects of these particles in the environment?
    - Uncertain Effects (Benign vs. Harmful)
    - Paucity of data regarding safety of the particles
    - Eventual release into the environment
- Are measurement tools sensitive enough?
  - OHS/Environmental Safety













### THE HYDROQUAL SOLUTION





#### **NANOTECHNOLOGY - The HydroQual Solution**

- Balancing the Risks vs. the Benefits
  - Understanding the Risks
  - Understanding the Environmental Impacts
- The HydroQual Solution
  - Develop
    - a set of high throughput commercially available tests (aquatic/terrestrial)
    - Risk based framework for evaluating the safety of new emerging markets
  - How
    - Systematic testing
      - Standard methods
      - State of the art microscopy techniques
    - Direct link with key academics and governmental organizations
    - Active involvement in various ad hoc nanotechnology advisory groups





#### **NANOTECHNOLOGY - Preliminary Data**

- Effects of nZVI vs ZVI Exposure on Barley
  - Standard Environment Canada methods
- What we looked at
  - Shoot and Root
    - Length/weight
  - Emergence
- What did we find?
  - Effects seen for Shoot weight and length at concentrations used for remediation
  - No effects seen in the Root weight/length or in emergence.
  - Bacterial Profile













### IS IT THE NEXT REMEDIATION MAGIC BULLET? Conclusions







#### **NANOTECHNOLOGY -** Remediation Magic Bullet?

- Yes,
  - Highly effective
  - Cost efficient
  - Smaller amounts of material need to be used
- *However*, expectations must be managed
  - 100% reduction of COC
  - Indefinite movement in the media
- Risks and Benefits must be measured carefully
  - Understand the full implications of exposure to both human and environmental health







# **THANK YOU**

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